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SHARED DISPLAYS: AN OVERVIEW OF PERCEPTUAL AND COGNITIVE ISSUES

Cognitive and Social Issues

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14. ABSTRACT
Large screen shared displays are a standard fixture in most command and control (C2) centers, but are often under-utilized. Many of the problems stem from the fact that shared displays are repeater displays from individual workstations. Scaling from workstation displays to large screen displays does not guarantee text will be large enough to be visible to all users. The colors and color range visible on the shared displays may not automatically match the colors displayed on individual workstations. Text and symbology overlays on maps are often not discernible when translated from individual workstations to shared displays. And when shared displays are repeaters, the operator's navigation and control icons, menus and pallets are visible on the shared displays and obstruct the view of displayed information. Shared displays often present what is called a common operating picture, or COP. The COP should be the basis of a common operational understanding, but they are often too cluttered, yet lack useful information. In today's complex environment of asymmetric warfare, effects-based operations and coalition forces, decision quality information is needed to support collaboration and synchronization of operations. This means delivering the right information at the right time in a clearly visible and easily understandable format that supports cognitive processes associated with situation awareness, decision making, and collaboration. The present paper will discuss perceptual and cognitive issues associated with shared displays and COPs in command centers.

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ABSTRACT

Large screen shared displays are a standard fixture in most command and control (C2) centers, but are often under-utilized. Many of the problems stem from the fact that shared displays are repeater displays from individual workstations. Scaling from workstation displays to large screen displays does not guarantee text will be large enough to be visible to all users. The colors and color range visible on the shared displays may not automatically match the colors displayed on individual workstations. Text and symbology overlays on maps are often not discernible when translated from individual workstations to shared displays. And when shared displays are repeaters, the operator's navigation and control icons, menus and pallets are visible on the shared displays and obstruct the view of displayed information. Shared displays often present what is called a common operating picture, or COP. The COP should be the basis of a common operational understanding, but they are often too cluttered, yet lack useful information. In today's complex environment of asymmetric warfare, effects-based operations and coalition forces, decision quality information is needed to support collaboration and synchronization of operations. This means delivering the right information at the right time in a clearly visible and easily understandable format that supports cognitive processes associated with situation awareness, decision making, and collaboration. The present paper will discuss perceptual and cognitive issues associated with shared displays and COPs in command centers.

1. INTRODUCTION

Large screen displays have become commonplace in military command centers, many of which are configured with multiple large screen displays. These displays are intended to complement individual workstation displays and enhance the warfighters' capability to perform the mission by supporting situation awareness, group decision making and collaboration, as well as synchronization of activity across the many specialized teams within the C2 environment. In broad, functional terms, the primary purpose of a shared display should be to help users integrate and manage information from a wide range of sources (Mynatt, Huang, Voite, & MacIntyre, 2003).

There are potential benefits for implementing large shared displays in the C2 environment. Large shared displays can provide a centralized location to display data derived from diverse sources, thus offloading individual workstation displays and facilitating team or multi-task performance. Large shared displays can quickly provide information to oncoming shift personnel or visitors to the C2 center. Shared displays have the potential to facilitate group understanding of organizational goals and objectives. However, very few of the personnel working in the C2 environment will attest to their usefulness. The shared displays are often regarded by those responsible for mission execution as "eye candy" for visitors, or "VIP screens", and they are largely ignored.

A primary goal of shared displays is to facilitate situation awareness (SA). For the C2 environment, it is important for personnel to see and understand what is happening, and to be able to take this information and put it into a larger context. But SA may not be the same for all individuals and all levels of command. Successfully implementing shared displays in the C2 environment means some important perceptual and cognitive issues.

Laboratory experimentation has made large display perceptual issues relatively easy problems to solve. Understanding the difference between the display types available with today's technology, how the location of the display interacts with the viewing distance and viewing angle, and measurements of color, contrast, and illumination, are all perceptual issues that should be addressed when implementing shared display systems.

A much more difficult challenge in designing large shared displays is determining how the system will deliver decision quality information to the warfighter. Unfortunately, many of the research issues central to large display cognitive issues, such as SA, task support and performance, and content relevance have still not been answered in a manner generalizable to the C2 environment. We can address the issues in this paper, but offering domain-specific solutions for shared display issues in the C2 environment falls under the purview of an analysis tool called a cognitive task analysis (CTA). We will discuss CTA in further detail later.

1.1 Recent observations

From July 2005 – May 2006 an Air Force Research Laboratory (AFRL) Human Systems Integration (HSI) Tiger Team evaluated the current state of HSI within the Air Operations Centers (AOC) and Distributed Common Ground System (DCGS) weapon systems. The team conducted observations at several AOC events including the Joint Expeditionary Force Experimentation 2006 (JEFX '06), an exercise for evaluating C2 tools in a simulated warfare environment. The findings were documented in an AFRL draft technical report submitted to the Command, Control, Intelligence, Surveillance and Reconnaissance (C2ISRC).

A general observation of our HSI Tiger Team was that the shared displays within AOCs were under-utilized. The under-utilization occurred primarily because the shared displays were mostly composed of repeater displays (the large displays duplicated, or *repeated*, the same information found on individual workstation displays). On these repeater displays, the operator's navigation and control icons, menus, and pallets, were often visible on the shared display and obstructed the view of displayed information. In a general sense, repeater displays can cause scaling problems when graphics and text are translated from individual workstations to large screen displays. When individual workstations use different display types (such as LCD or plasma displays), color reproduction on shared display projection screens may not match the color output of individual workstations. Text and symbology map overlays, repeated from individual workstation displays, may not be large enough to be visible to all users of shared displays.

A typical shared display in AOCs is the common operating picture (COP). While the COP should be the basis of a common operational understanding, it often lacks useful information and is cluttered with data and graphics. The COP display at JEFX '06 displayed all or most of the air assets with no information about their status or relevance. Key operational areas such as air refueling and close air support were not shown.

Darling & Means (2005) interviewed a group of 16 participants at JEFX '04 where a large shared display was present during the exercise. Eight participants in the study reported they never looked at the shared display. Five of the other 8 participants reported looking at the shared display only on occasion. These participants reported the COP information on the shared display was “not appropriate for me/for my level.” One reason for this may be that the shared display was a repeater of individual workstations, as reported by one participant in the Darling & Means study. Three noteworthy recommendations for shared display design resulted from their study: 1) make sure the shared display is not a repeater of individual workstations; 2) provide small, collaborative displays for sub-groups working within the C2 environment; and 3) provide high-level data that is graphically represented.

The overarching message in the above recommendations is that display designers need to provide C2 personnel with the ability to quickly see and interpret information (text and graphics) on shared displays. The primary goal of this paper is to present an overview of perceptual and cognitive human factors issues associated with shared display implementation. This paper is organized into three main sections: 1) defining shared displays; 2) perceptual issues; and 3) cognitive issues. We will conclude with a brief outline of current and future research programs at the Air Force Research Laboratory Human Effectiveness Directorate. Unfortunately, time and space constraints prevent the authors from providing in-depth information a reader might want or need to plan and implement a shared display system. In an effort to provide as much information as possible, a more detailed list of readings and references can be found in Appendix A.

2. WHAT IS A SHARED DISPLAY?

So what exactly is a shared display? The term *shared display* covers a range of definitions, even within the C2 environment. A general definition – large-scale computer information systems designed to provide decision support and facilitate situation awareness – is not a complete representation of either the form or function of a shared display. Shared displays come in many sizes, forms, and configurations.

In our technological era, we generally represent *display* as a form of electronic media (such as a desktop or wall-mounted monitor), but a flipchart or whiteboard can, by form (and function), be considered a shared display. When people think of shared displays, they may imagine large wall displays viewable by very large groups of people, like room-spanning displays found in C2 centers, or a bank of airport computers reporting departure and arrival times. But shared displays come in many sizes. They can be designed to support the activities of small groups (eight people of less), large groups (eight to 20 people) and very large groups (20+ people).

Figure 1. Large Group, Interactive Display.

Small group shared displays function much like computer monitors found in desktop configurations, and generally utilize either a plasma or LCD flat panel display screen. Mounted or portable displays measuring approximately 36" – 48" would fall into the small shared display category. The usual function of a small display is to facilitate the collaboration and interaction of two or more people, and displays of this size are becoming ubiquitous in military, business, and academic settings. However, these displays can also serve as a non-interactive platform for public information sharing, general notification, and as support displays for larger systems.

Figure 2. Large Group Display – Tiled Configuration.

Large group shared displays can accommodate groups of 8-20 people and generally range in length from 6' – 15'. Besides functioning as both a collaborative and an interactive tool, large shared displays have the added benefit of summarizing and sharing information for large groups of users. The large shared display in Figure 1. was designed by the AVID (Advanced Visualizations and Interactive Displays) team at Air Force Research Laboratory Information Directorate. The display consists of approximately 3.9 million pixels spanning an 12' x 3¼' area with a 9' x 2¼' viewing area (Alvarez, Jedrysik, & Zhang, 2006). Since current technology often does not economically provide the resolution needed for quality viewing for a single display of this size, displays for large groups often consist of an expanse of connected projection, plasma, or LCD displays. The convergence of displays may be invisible to the user (seamless) or appear as many displays side-by-side. Figure 1. illustrates an invisible, or seamless, connection of three rear projection screens; Figure 2. (also a large group shared display) is an example of a tiled display.

Figure 3. Very Large Group Shared Display at an Air Operations Center.

Very large group shared displays are often referred to as Knowledge Walls (K-Walls) or DataWalls, and are designed to be viewed by more than 20 people simultaneously. One of this paper's authors observed an AOC exercise where eight large shared displays covered a wall measuring 102 feet in length. This shared display was simultaneously viewed by more than 100 people. Figure 3. shows an example of a very large group shared display in a typical AOC. In contrast to small and large shared displays, very large shared displays have traditionally functioned *primarily* as a summary and information sharing tool with little user interaction. Direct interaction (e.g., data input) is usually limited to a small group of authorized users who update or change information on the display. The potential size of very large group shared displays is, for the most part, constrained only by the surrounding building structure. However, bigger may or may not be better, and implementing a large shared display requires careful consideration of both perceptual and cognitive issues related to human-computer interaction (HCI).

3. PERCEPTUAL ISSUES – Can I see it? Can I read it?

If the user of a shared display cannot see or read the information presented, the display has little or no value in facilitating situation awareness or supporting task performance. There are capabilities and limitations for both the displays and the operators within the C2 environment that affect how information and data on shared displays are perceived. One of the first issues that should be addressed when implementing a shared display system is the interaction of display location and user location. Other perceptual issues include display measurements, display luminance and contrast, ambient illumination of the C2 environment, general display readability, and color reproduction capabilities of the shared display. The following section is an overview of current guidelines and common display measurements associated with these issues.

3.1 Location – Viewing Distance and Viewing Angle

Eye Rotation Only

- Optimum: 15° left to right
- Maximum: 35° left to right
- Optimum: parallel and down 30°
- Maximum: 25° above parallel; 35° below parallel

Head Rotation Only

- Optimum: straight ahead
- Maximum: 60° left to right
- Maximum: 50° above and below parallel

Eye and Head Rotation

- Optimum: 15° left to right
- Maximum 95° left to right
- Optimum: parallel and down 30°
- Maximum: 75° above parallel

Table 1. Eye and Head Rotation Guidelines (in degrees).

Large shared displays in the C2 environment are designed to serve a large number of co-located users. But co-located does not imply the users will have the same perspective with respect to the shared display. Not all users can be seated directly in front of or at an optimum distance from the shared display; because the location of the shared display will constrain both the user's viewing distance and angle, location of the display should be a major consideration in the design process. (Alvarez et al., 2006). Display to user measurements should be taken for all C2 personnel with regard to operator head rotation, viewing angle, and visual acuity.

The reason these measurements are so important is that a user's repeated physical movements beyond a comfortable range of motion may induce physical strain and fatigue. If a user is experiencing physical discomfort due to display proximity, the discomfort may also interfere with their ability to perceive information presented on the display. Table 1. outlines easy-to-follow guidelines for optimum eye and head rotation applicable both to individual workstations and shared displays (Ebben, J., CPE, MIL-STD-1472D in Da-Lite, 1998). These guidelines can be used in conjunction with the planned location of the display(s) to determine the optimal placement of C2 personnel, or with current C2 personnel layout to determine the best location for the display(s). Of course the best place to sit with respect to a display is directly in front of it, but using 'directly in front of' as a description of location relative to a display is ambiguous without taking into account the distance from the display screen. Users closer to the display screen will have a wider field of view (viewing area relative to position), and hence require the greatest head rotation and physical range of motion.

Character and symbology size requirements are also affected by the angle and distance between the user and the display. The formulas shown in Figure 4. demonstrate character height requirements for legibility as a function of visual angle and viewing distance, where visual angle is the angle subtended by the character on the pupil and viewing distance is the distance between the observer and the viewed character (Dugger & Barley, 1999). For example, if the shared display user is expected to read the information displayed on a screen, the height of all lowercase characters must subtend *at least* 10 minutes of arc on that viewer's retina. A less rigorous way of saying that is to state that there must be ¼ inch of lowercase character height for every seven feet on-axis viewing distance (Da-Lite, 1998). On-axis viewing means the observer's line-of-sight is perpendicular to the display screen; off-axis viewing means the observer's angle relative to the display is non-perpendicular.

On-Axis viewing

$$\omega_1 = \frac{\text{3438 x Symbol Height}}{\text{Viewing Distance *}}$$

Off-Axis viewing

$$\omega_2 = \frac{\omega_1 (\cos \alpha)}{\text{Viewing Distance *}}$$

ω = Subtended angle in minutes of arc

α = Off-axis angle

* = Distance from viewer to screen along line-of-sight

Figure 4. Subtended Angle Equations.

3.2 Common Display Measurements

With the display technology available today, there are three main categories of shared display monitor types: front or rear projection, LCD, or plasma. Each shared display will have its own specific properties pertaining to color, contrast, and screen illumination. Display and measurement equipment set up is critical to any display evaluation. All measurements should be conducted in accordance with applicable military standards and the Video Electronics Standards Association (VESA) display measurement standards. The calibration guidelines and set up procedures are set forth in the VESA Flat Panel Display Measurements Standard, Version 2.0 Publication. Measurement devices should be properly calibrated to assure that all measurements are traceable to National Institute of Standards and Technology (NIST) standards (Aleva & Meyer, 2004).

While the selection of measurements to be performed on any display will depend on where and how the display is intended for use, there are a number of measurements applicable to most display types. These include:

- Display Luminance Range and Contrast Ratio
- Viewing Angle Effects upon Luminance and Contrast
- Ambient Illumination Effects upon Contrast
- Readability
- Display Color Gamut
- Uniformity of Luminance and Color
- Power Consumption

3.2.1 Display Luminance Range and Contrast Ratio

The difference between the luminance of full screen white and full screen black gives us the luminance range of the display. This is important if the display is to be used in both daytime and nighttime conditions. The luminance range also constrains the number of discriminable gray shades that the display can produce. This is particularly important for the display of continuous tone imagery. The display contrast ratio (the ratio of brightest white to darkest black) is important for legibility, particularly with high spatial frequency information such as alphanumerics (Aleva & Meyer, 2003).

Display luminance range and contrast ratio are determined by measuring the luminance of full screen white and full screen black. These two measurements are typically made in the center of the display. The units are typically expressed in candelas per meter squared (cd/m^2). The full screen white measurement requires maximum output from each of the primary display elements, Red, Green and Blue. For a display system with 8 bit color depth the inputs would be: red = 255, green = 255, blue = 255. For systems with more color depth the resulting inputs would be increased accordingly to the maximum value possible. Black is accomplished by setting the Red, Green and Blue to 0,0,0. The full screen white and black luminance values are also used to calculate the Contrast Ratio of the Full Screen. This contrast ratio is expressed mathematically by the equation: $C = L_W / L_B$ where C is the contrast ratio, L_W is the luminance of the full screen white measurement and L_B is the luminance of the full screen black measurement.

3.2.2 Viewing Angle Effects upon Luminance and Contrast

Larger viewing angles can distort luminance and contrast, so measurements are made to assess what happens when a display is viewed at angles other than the standard on-axis perpendicular viewing condition. First, a center sample of the display is measured for luminance and contrast. Subsequent measurements are taken in the same center area, but the angle between the measuring device and the display is changed. Either the display or the measuring device can be rotated or repositioned to assure that the same area of the screen is being measured. It is important to measure the same area of the display to assure that spatial inhomogeneity does not contaminate the measurements. White luminance and black luminance are measured to assess the changes in luminance and contrast ratio that may come about as an effect of viewing angle. Viewing angles of +/- 30 degrees horizontal and +/- 15 degrees vertical are generally measured as a check of a manufacturer's viewing angle performance specification; however the selection of what viewing angle to assess can be driven by a particular application (Aleva & Meyer, 2003).

3.2.3 Ambient Illumination Effects upon Contrast

The C2 environment is typically a large, open space with higher-than-normal ceilings with variety of general and task lighting configurations. Ambient illumination, or general non-task lighting, is addressed by measuring display contrast in the same lighting environment in which the display will be used. Ambient illumination striking the surface of the display may be reflected back to the viewer's eye, thus reducing the perceived contrast of the display (Aleva & Meyer, 2003). The measurement of the full screen black is particularly susceptible to the effects of ambient lighting and room reflections when measuring display luminance. Overall, projection displays are more sensitive to ambient illumination and usually perform better when ambient room lighting is set to a low level.

If the display luminance is not high enough and the display contrast is too low, the images on the display will not be legible, at least not rapidly legible. The human eye adjusts its aperture (pupil) size depending on the ambient lighting, and can restrict the amount of light from a display. The evaluation of a display to determine its hi-ambient legibility involves evaluating how well it maintains good contrast in lighting conditions typical for where the display will be used.

3.2.4 Readability

To insure readability, the display should be free of disturbing artifacts such as shadowing, lines, and jitter. This can be evaluated subjectively.

3.2.5 Display Color Gamut

A color gamut is the range and combination of colors that can be produced by a display system. The gamut is dependent on display type (LCD, projection, plasma) and is generally described in mathematically defined CIE color space. CIE color space represents the full spectrum of colors visible to the human eye.

To determine a display's color gamut, measurements are taken perpendicular to the display screen. Three color measurements are necessary to determine a display's gamut: 1) Red is measured at maximum output with Green and Blue set to zero; 2) Green is measured at maximum output with Red and Blue set to zero; and 3) Blue is measured at maximum output with Red and Green set to zero. The results provide the triangle vertices shown in Figure 5. Straight lines are drawn between vertices (Green, Red), (Green, Blue) and (Blue, Red) to form the triangle that defines the display color gamut (Aleva & Meyer, 2003). Figure 5 (a, b, and c)

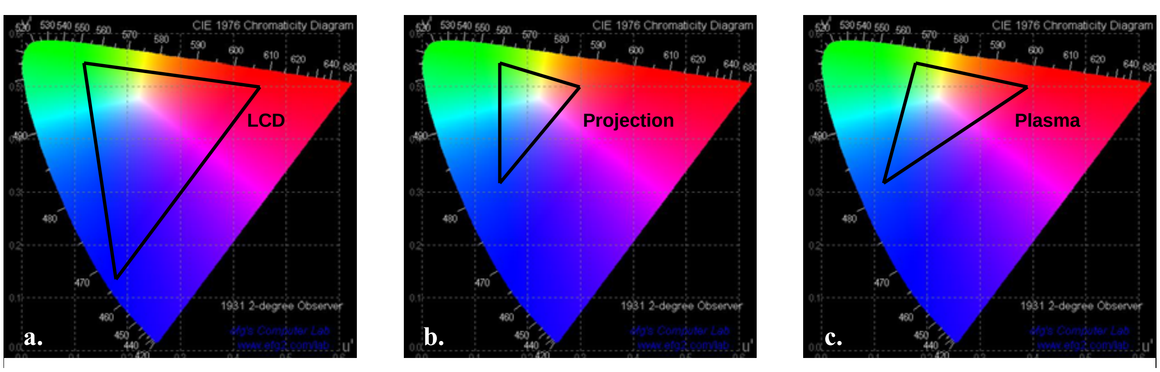

Figure 5. Color gamuts for LCD, projection, and plasma displays.

shows the color gamuts for an LCD, a projection, and a plasma display, respectively. Note that none of the displays are capable of producing all the colors the human eye can detect, but of the three displays types, the typical LCD display produces the largest color gamut. Viewing angle may also affect the color gamut. To insure consistent color effects, it is prudent to take additional measurements (similar to measurements for luminance and contrast using viewing angles of +/- 30 degrees) to determine how a display's color gamut is affected by off-axis viewing.

3.2.6 Uniformity of Luminance and Color

Uniformity of luminance and color are especially important if the display format employs color or brightness coding. A red symbol should look the same no matter where on the display it appears. Uniformity of luminance and color refers to the variability that exists across the area of a full screen display when, in theory, different areas of the display should have identical luminance and color characteristics.

Measurements are made at specific points on the full screen white display to determine how much luminance and color variation is present in a full screen white display. Typically, either five (four corners and center) or nine (four corners, center, and midpoint of top, bottom and each side of the display) points are measured. The deviations for luminance are reported as a percentage difference from the maximum white measured. Color differences are reported in terms of u' v' differences. The same procedure is followed for each of the red, green, and blue display primaries (Aleva & Meyer, 2004).

3.2.7 Power Consumption

Power consumption measurements should be made for the worst case, where the display is adjusted in a manner that the maximum possible power consumption occurs. In cases where this is atypical and where typical settings are available and achievable, power consumption measurement can be made at those settings or conditions.

4. COGNITIVE ISSUES – Can I use it?

This section provides a synopsis of the important cognitive issues associated with large shared displays. As we mentioned earlier, conclusive research, especially with respect to domain-specific C2 environments, is limited. However, we have included some noteworthy study results that may be generalizable to strategic, operational, and tactical command center situations.

- Situation Awareness
- Cognitive Task Analysis
- Data Visualization
- Information Sharing and Display Interaction
- Display Control

4.1 Situation Awareness

What exactly is situation awareness, or SA? Endsley (1988) defined SA as a knowledge-based understanding of an environment and provided a three-level description: 1) the perception of elements in a situation; 2) the comprehending of what those elements mean; and 3) the use of that understanding to project future states. Is SA important for the C2 environment? Smallman, Oonk, & Moore, (2000) conducted structured interviews with Joint Operation Center (JOC) command elements at the Global 2000 War games to ascertain their needs for a shared display to facilitate SA. The command elements are in agreement – rapid, shared SA is a high priority.

Mynatt et al. (2003) have proposed several system network applications to help facilitate SA. Most applicable to the C2 environment are what they term Collaboration Space and Active Portrait. These proposals consider how communication networks affect decision-making and the group environment as a collective whole. Collaboration Space is an interactive application that provides a platform for individuals to request assistance. A user enters a request into the interface, which in turn allows other individuals to sequentially create and edit the original communication. The continuous, and trackable, communication threads can help to alert many users at once and also reduce mental workload. An application like Collaboration Space could be implemented in a shared display system via Active Portrait. Active Portrait is graphic-based application that uses icons, shown in plan view, to illustrate the individuals in the C2 center. Icons represent individuals; when icons are activated, current task and status are displayed. Applications like these may be useful cognitive tools that could support SA by allowing C2 personnel to view individual and group activity with a quick glance to the shared display.

If applications are designed to facilitate SA, how will we know we have achieved SA? Will the answer be objective (observable or measurable) or will it be subjective (reported)? A recent study compared how large shared displays and smaller, desktop displays facilitated SA and reduced mental workload (Emery, L., Catchpole, K., Macklin, C., Dudfield, H., & Myers, E., 2001) during a simulated C2 exercise at the Joint Force Air Component Commander's Headquarters (JFAC HQ). The researchers found no significant difference between the display sizes when participants were measured using the NASA TLX (a mental workload assessment) and SART (an SA measure). However, in an assessment of shared displays used over a three-year period at UK JFAC HQ, subjective data reported strong support and preference for large shared displays. At UK JFAC HQ, respondents reported the shared display provided both increased SA and decision support.

But at this point in time, questions such as "What is SA?" and "How do I know I have SA?" have not been satisfactorily answered. For the C2 environment, it is likely the appropriate answers will be found in application-based and domain-specific research studies. However, facilitating SA with large shared displays, regardless of the user or domain, will only be possible if the displays present the right information at the right time in an easily readable and understandable format. In order to determine what information would be beneficial on shared displays, including the usefulness of specific software applications designed to facilitate SA in the C2 environment, research psychologists use an analysis tool called a Cognitive Task Analysis, or CTA.

4.2 Cognitive Task Analysis

At AFRL, we use Cognitive Task Analysis (CTA) for display design in complex information environments. CTA is a set of methods and tools for understanding the mental processes involved in task performance (Klinger & Hahn, 2003). A normative approach to work analysis, CTA allows psychologists to understand exactly what tasks are to be performed and what information is needed to perform those tasks. CTA also addresses the task information source (where you get the information you need to perform the task) and how this information is shared between interfaces, individuals, groups, and the organization (Vicente, 1999).

For a shared display CTA, the emphasis would be on identifying how operators should use and interact with shared displays to facilitate task performance. The mental processes involved in this type of interaction cannot be understood simply by observing behavior, particularly if the tasks being performed are cognitively complex. CTA focuses on collaboration requirements within individual cells/teams as well as coordination/synchronization between cells/teams. CTA documents cell/team functions and tasks, information and decision requirements and flow of information within and between cells/teams. Format and interpretation of information are examined as well as strategies and timing of task performance. The information obtained in a CTA is elicited from subject matter experts (SMEs) through in-depth interviews as well as observation. These SMEs will be persons with current or recent experience in the positions of interest. In the C2 environment, CTA would help identify and clarify what individual or team task goals should be, how they will be supported by the display, and how these goals should be achieved.

4.2.1 Task Support

To design an efficient shared display that supports task performance, C2 command must have a full understanding of all the tasks that require display support. CTA will be helpful identify and categorize task types. Tasks that require support by system applications can generally be put into one of three categories: 1) individual tasks; 2) collaborative tasks, and 3) synchronic tasks.

C2 personnel perform *individual tasks* on a daily basis. These include submitting reports, handling administrative responsibilities, and monitoring system status. Individual tasks do not generally require direct interaction with other C2 personnel. Large shared displays can be helpful in providing individuals access to the data needed to support individual task performance.

In *collaboration tasks*, individuals or teams pull together many pieces of the data to achieve task goals. Many C2 tasks require more than one personnel unit. These tasks may require either small, co-located groups (all persons in physical proximity to each other), or partnerships of individuals located in different areas of the C2 center. One team may need information about weather, another team may need information about enemy location, but both pieces of information are needed to complete the task. Presenting appropriate information for multi-team tasks on the shared displays may facilitate collaboration task performance by reducing error and time on task.

Synchronic tasks are collaborative tasks with temporal constraints. For example, the information one individual or team needs must be received simultaneously with information another individual or team needs to meet the task goal. In this situation, it would be important to present information on the shared display in a timely fashion in order to facilitate task performance.

4.3 Data Visualization

A important issue to achieving SA in the C2 environment is data visualization. Presenting information on the shared display depends on task requirements, performance goals, and mission objectives. Some important questions include:

- Should applications supporting user tasks be rendered in a 2D platform, in 3D, in 4D (3D plus time) or in combination?
- Will the shared display contain low-level data or high-level data?
- If low-level data are presented, how will the user access links to higher-level information, or vice versa?

We do not have room in this paper to provide a complete review of available data visualization software, but we will illustrate one example in an attempt to help the reader understand the general idea of applications designed to support complex data visualization.

In a recent study, Polys et al. (2005) showed that embedded-in or linked-to information (e.g., moving from high-level data to low-level data) may be more navigable and understandable if the display contains 3D visualization software, such as virtual space or 3D object display. They compared two applications – Viewport Space and Object Space – and examined the interaction of these applications with a small display size (desktop) and a larger display size (nine-monitor tiled display). Both applications used a navigable 3D environment filled with information objects. Spatial coupling, or labeling of the individual objects themselves, was used in Object Space. Viewport Space used *tethered labels,* removing the spatial coupling and presenting the object information in a single display area (in this case, the top of the screen), but tethered to the information object.

The results of this study showed tight spatial coupling (Object Space) yielded improved performance for search and comparison tasks on a large display size. However, on a small display, Viewport Space (tethered arrangement) resulted in improved task performance. For the C2 environment, these results suggest supporting task performance may be dependent on display size and using the same applications on both individual workstations and shared displays may be problematic for some types of task performance.

4.4 Information Sharing and Display Interaction

The sharing of information between individual workstations and shared displays is another vital function in the C2 environment. Mulgund, Travis, Standard, Means, & Burgman (2005) provide an overview of the C2 structure of the shared display/individual workstation relationship, including information contained therein. They separate display communication interaction into two categories: *pushing* information from individual workstations to shared displays, or *pulling* information from shared displays to individual workstations. Pushing information makes it possible to quickly distribute valuable information to the entire C2 environment. Pulling information allows individual workstations to drill-down into high-level data provided on shared displays. The researchers further elaborate these concepts by incorporating them into a system architecture called SIDEview. An example of an interactive application, SIDEview supports system access via hand-held devices (e.g., PDAs) or tablet PCs.

PDAs are ubiquitous today and most people have some idea about interacting with these small, electronic data devices. Wireless and mobile, this type of network communication allows users to interact with shared displays without having to use connected peripherals, eliminating workstation dependence. Myers et al. (2003) studied the use of PDAs as a data sharing middleman for larger data networks. The PDAs were shown to be a successful way of moving (in this case, *pulling*) information from shared displays to individual workstations. Their studies also showed using PDAs in this fashion also resulted in reduced task performance time and errors compared to using traditional data transfer methods or the display manufacturers remote control device.

Myers, et al. (2001) have also developed an interactive style of sharing data. Semantic *snarfing* uses a laser or other pointing device to identify a relevant area of interest on the shared display (or individual workstation). Once identified, the data area can be copied directly to the other display.

Biehl & Bailey (2004) tackle the issue of collaborative information sharing with a system called ARIS, or Application Relocation in an Interactive Space. Used in conjunction with other running applications and accessible through both individual workstations and shared displays, ARIS organizes the physical workspace (the AOC) using an iconic map of the space, similar to the application Active Portrait (discussed earlier). ARIS users can relocate applications among screens without being physically close to or physically moving among them, allowing shared information to be located on as few or many displays as deemed appropriate.

Multiple users, however, may unintentionally interfere with the mission due to network constraints. One reported multi-user issue is that some system configurations cannot recognize simultaneous input from users, thus causing heavy-user transparent access problems (Alvarez et al., 2006; Jedrysik, Moore, Brykowytch, & Sweed, 1999). This might include visible cursors or menus inadvertently obstructing other relevant data. To combat this, researchers are looking to devise non-physical ways to interact with large shared displays. Interacting with speech could alleviate some of the problems associated with multiple-user physical access. Jedrysik et al. reports a promising speech recognition software called HARK from BBN Systems and Technologies that is *speaker independent*. Most speech recognition software available today requires many hours of training (for *each* user) with the application before it can be used efficiently. The HARK system can immediately recognize many different users' voices without any training on the part of the user.

4.5 Display Control

If it is a small or large group shared display (up to 20 people), display access (data input/output capabilities) by all members may be beneficial to overall group performance. However, very large group shared displays may not benefit from equal access and most C2 centers do not allow equal access to the data input process. Research suggests that multiple person interaction with shared displays is cognitively demanding on the entire team of users and this type of interaction should be implemented with caution. It may be more efficient and effective for only a few individuals or one small team to be responsible for the information presented on the shared display (Bindle, 2005). Another option would be to have the system configured for automatic updates and information uploads, completely eliminating direct access (and possible error) to the display.

According to focus groups conducted by Dugger et al. (1999) at the Integrated Command Environment (ICE) lab at the Naval Surface Warfare Center Dahlgren Division, four general guidelines for shared display control emerged: 1) control of the display should be automated to reduce operator error; 2) a team leader should have discretionary capabilities to override the automation; 3) the team leader should notify other members when an override has been initiated; and 4) the team should be able to create and implement pre-sets to the system.

As a result, some command centers use a small team called an *anchor desk* to supervise the information flow through the center. This includes not only the flow to the shared display, but also a connection with and between individual workstations. According to a CTA done at the Global 2000 War Game by Smallman et al. (2001), anchor desks could be used to disseminate briefs, risk assessment information, communication status, weather information, and asset allocation information. Their study also suggests that if there are changes made to shared displays, an alerting mechanism between the anchor desk and individual workstations should be utilized.

5. ARFL/HECV RESEARCH

The researchers at Air Force Research Laboratories/Human Effectiveness Directorate are involved in several research areas with respect to large shared displays, including change detection and awareness, 3D data visualization, and 4D (3D with time dimension) tailored COPs.

5.1 Change Detection and Awareness

The concept of shared display change awareness is relatively unstudied in the C2 environment. To achieve SA, shared display users must be quickly made aware of changes in information and situation status. In a busy C2 environment, we want to investigate ways to alert the user to changes. We hope to understand ways to support the recognition of and attendance to important or relevant data changes on shared displays, how best to notify the user of relevant changes to data and graphics, and whether the alerts we employ should be visual, auditory, tactile, or multi-sensory. We are currently designing studies to determine what kinds of alerts to use with different groups of users, where to place the alerts within the system, and if alerts types are dependent on activity levels in the C2 environment. Once we establish some guidelines, we want to investigate temporal change awareness. Change awareness, with respect to shared displays in the C2 environment, means understanding the variables that affect the user's ability to detect specific changes on shared displays.

5.2 Tailored Common Operating Pictures

Most AOC large shared displays include a Common Operating Picture (COP). Generally it is created from a large database of information with the goal of presenting a generic operating picture for all to see. But the convergence of data from many disparate sources can result in the presentation of overlapping and redundant data, and providing only a top level composite view of the Air Tasking Order plan and execution. Current COPs are generally very cluttered and useful to no one. AFRL observations of JEFX '06 suggest that teams in the Combat Operations Division would benefit from shared COPs that are tailored to their particular task requirements. Bindl (2005) suggests that COPs may be flawed by being subject to varied interpretations based on the perspectives of the observers. The further away the observer is from the process of developing the COP for his or her particular needs, the greater chance the observer will have of misinterpretation.

We are currently conducting a cognitive task analysis (CTA) of the Combat Operations Division to determine which cells/teams within the division would most benefit from tailored COPs and how these tailored COPs might facilitate coordination/synchronization between cells/teams. This analysis will identify the decisions, judgments, cues, tasks, situation awareness elements and collaboration requirements that are critical to mission success. This data will be used to determine what information would be most useful on shared displays and whether some shared displays should be focused or tailored for specific cells or teams. Tailored COP prototypes will be developed and evaluated at JEFX '08. We will further evaluate how shared display usage might complement individual workstation usage and how shared displays might be made interactive for collaboration.

5.3 Data Visualization

The advent of greater computer processing capability and low cost gaming engines currently enables visualization of 3-D information on flat screens allowing the user to rotate, tilt, zoom in and out and fly through the visualization. Preliminary discussions with warfighters indicate that map displays and multidimensional networks are good candidates for 3-D visualizations. While these visualizations are aesthetically appealing, little research has been done and few guidelines exist for display of 3-D information. Beyond 3-D visualizations on flat screens, prototype 3-D display hardware devices are becoming available and are of interest for applications such as Common Operating Picture in Air Operations Centers. This effort will include, but not be limited to, examining eyepoint and perspective, rotation and tilt, actual versus exaggerated elevation, navigation, use of multidimensional icons and knowledge glyphs within 3-D visualizations, interaction techniques and working between 2-D and 3-D workspaces.

6. SUMMARY

Two important goals of large shared displays in the C2 environment are to facilitate SA and support task performance. It is interesting to note that in 1986, McNeese & Brown published a report outlining both perceptual and cognitive research issues related to large group displays. The perceptual issues they reported include display format (size/type/location), information density (clutter), and information representation (text or graphics/high- or low-level data). Cognitive issues reported include task complexity (performance), display allocation (information sharing and access), and mental workload.

Today, McNeese and Brown would appreciate that researchers have a good understanding of perceptual issues pertaining to large and shared displays, including display location, viewing angle, viewing distance (between display and user), luminance and contrast, and color reproduction capabilities, and problems in these areas can easily be overcome. These issues are very important, and implementing large display systems without addressing them could cause difficulties in perceiving and reading the data presented. This could potentially lead to under-utilization of a shared display system.

However, the cognitive issues regarding shared displays have yet to yield generalizable guidelines. Facilitating SA and providing task support are two main overarching goals for large shared displays, but often the ultimate function of the displays, especially within C2 centers, remains ambiguous. Current shared displays are often designed to provide top-level composite views of the air tasking order (ATO) plan and execution, but with current implementation, this does not appear to be an efficient and effective use of large display technology.

CTAs should be conducted to identify relevant tasks and task types, who would benefit from different types of information on the shared display, and how collaborative task performance may be enhanced with shared displays. Continued research in the areas of display system interaction and data visualization is needed to achieve optimal HCI (human-computer interaction) in the complex relationship between individual workstations, shared displays, and C2 personnel.

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Appendix A

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Shared Displays

An Overview of Perceptual and Cognitive Issues

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Human Effectiveness Directorate

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Overview

Defining Shared Displays

Perceptual Issues

Cognitive Issues

Current AFRL/HE Research

Defining Shared Displays

What are they?

Computer information systems designed to facilitate situation awareness and provide decision support

Defining Shared Displays

Characteristics

Computer information systems designed to facilitate situation awareness and provide decision support

- ***Electronic media***
- ***Display type – LCD, plasma, projection***
- ***Interactive v. non-interactive***

Defining Shared Displays

Domains

Computer information systems designed to facilitate situation awareness and provide decision support

- ***Military***
- ***Public access***
- ***Academics***
- ***Industry***

Defining Shared Displays

Display Size

Computer information systems designed to facilitate situation awareness and provide decision support

- ***Small group – 8 people or fewer***
- ***Large group – 8 to 20 people***
- ***Very large group – 20+***

Defining Shared Displays

Small Group

Computer information s
situation awareness an

- *8 people or fewer*
    - *Usually interactive*
    - *Collaborative*
    - *Mounted or portable*

www.tekpanel.com

Defining Shared Displays

Large Group

Computer informa
situation awarene

- 8 – 20 people
  - ***Tiled display***
  - *Collaborative*
  - *Interactive*
  - *Portable*
  - *Summary tool*

Defining Shared Displays

Large Group

Computer informatic
situation awareness

- *8 – 20 people*
  - ***<u>Seamless display</u>***
  - *Collaborative*
  - *Interactive*
    - *Handhelds*
    - *Voice*
    - *Touch*

Defining Shared Displays

Very Large Group

Computer information sy
situation awareness and

- *20+ people*
  - *C2 environment*
  - *Summary tool*
  - *Non-interactive*
  - *Repeaters*

Defining Shared Displays

Very Large Group

Computer information systems de
situation awareness and provide

- *20+ people*
  - *"Data" Wall*
    - Generic term for wall display
  - *"Knowledge" Wall*
    - A concept for *the application of decision support tools to a data wall* that supports group decision making & collaboration

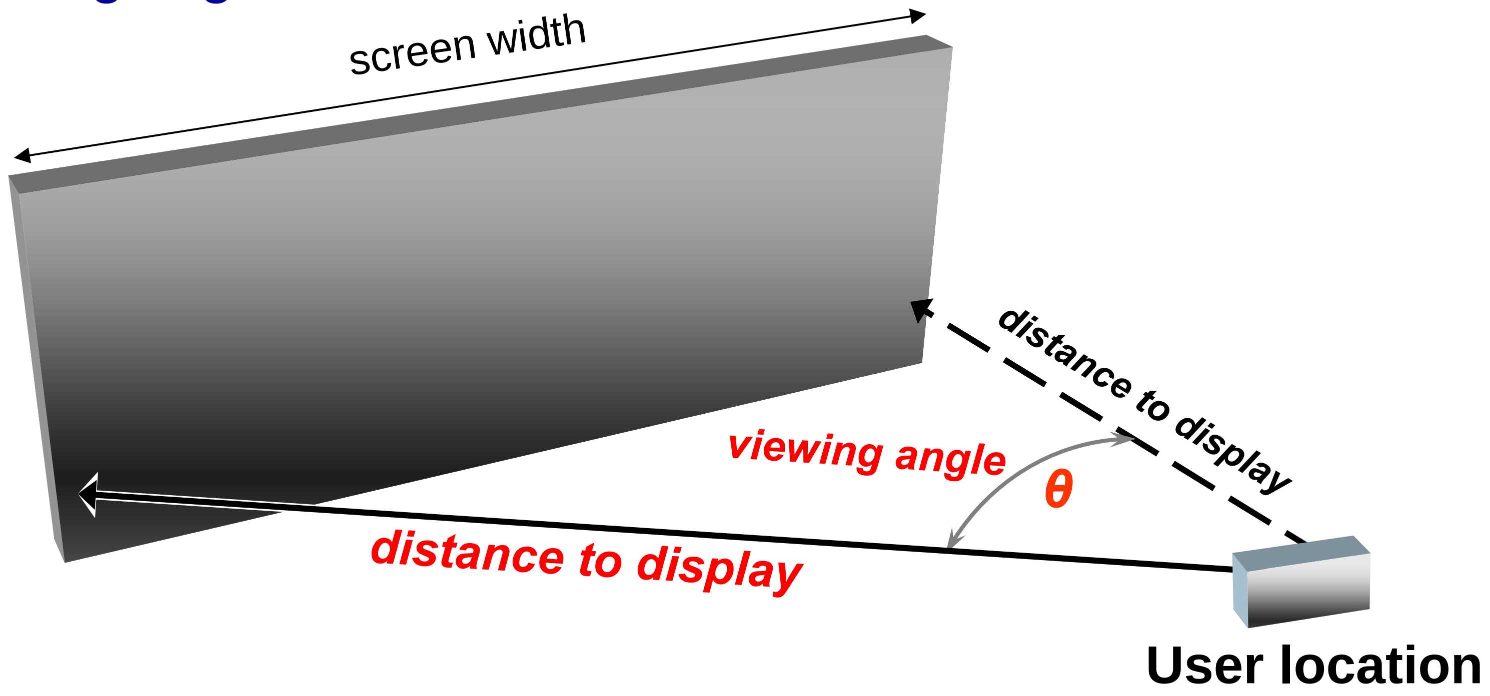
Perceptual Issues

Can I see it? Can I read it?

- Location of the display
- Viewing angle and distance
  - *Head rotation*
  - *Eye rotation*
  - *Text size*
- Contrast
  - *Ambient illumination*
- Readability
- Color selection

Location of the Display

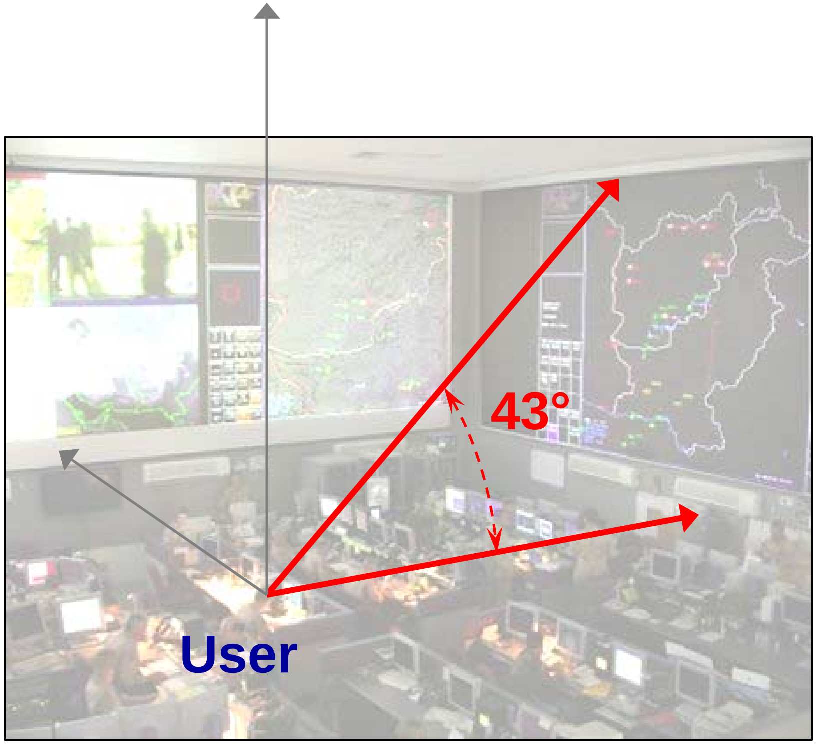
- Viewing distance
- Viewing angle



Location of the Display

Eye Rotation

- Optimum – 15° left to right
- Maximum – 35° left to right
- Optimum – parallel down 30°
- Maximum - 25° up, 35° down

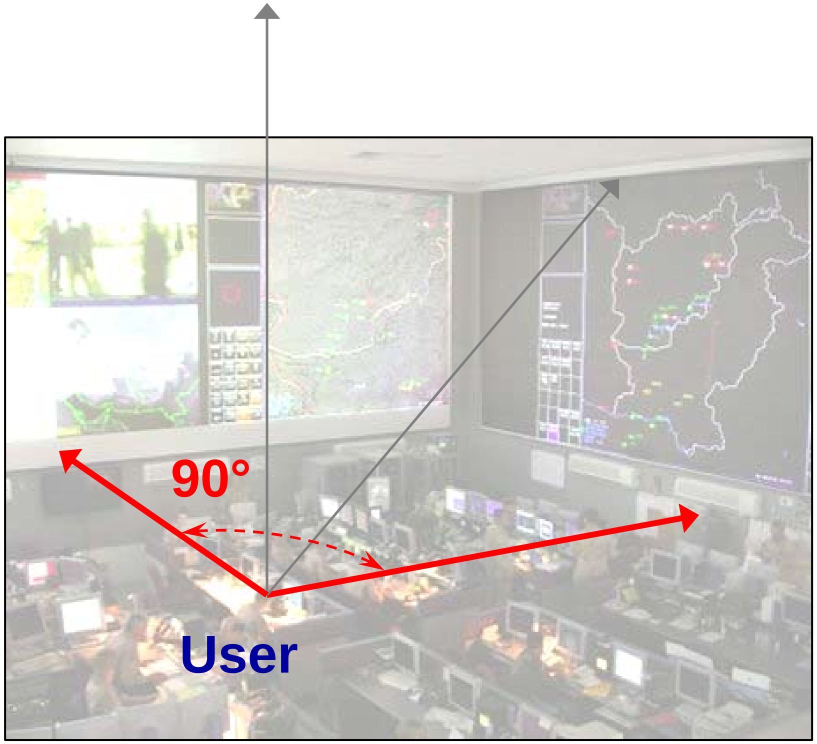


Source: Ebben (1998)

Location of the Display

Head Rotation

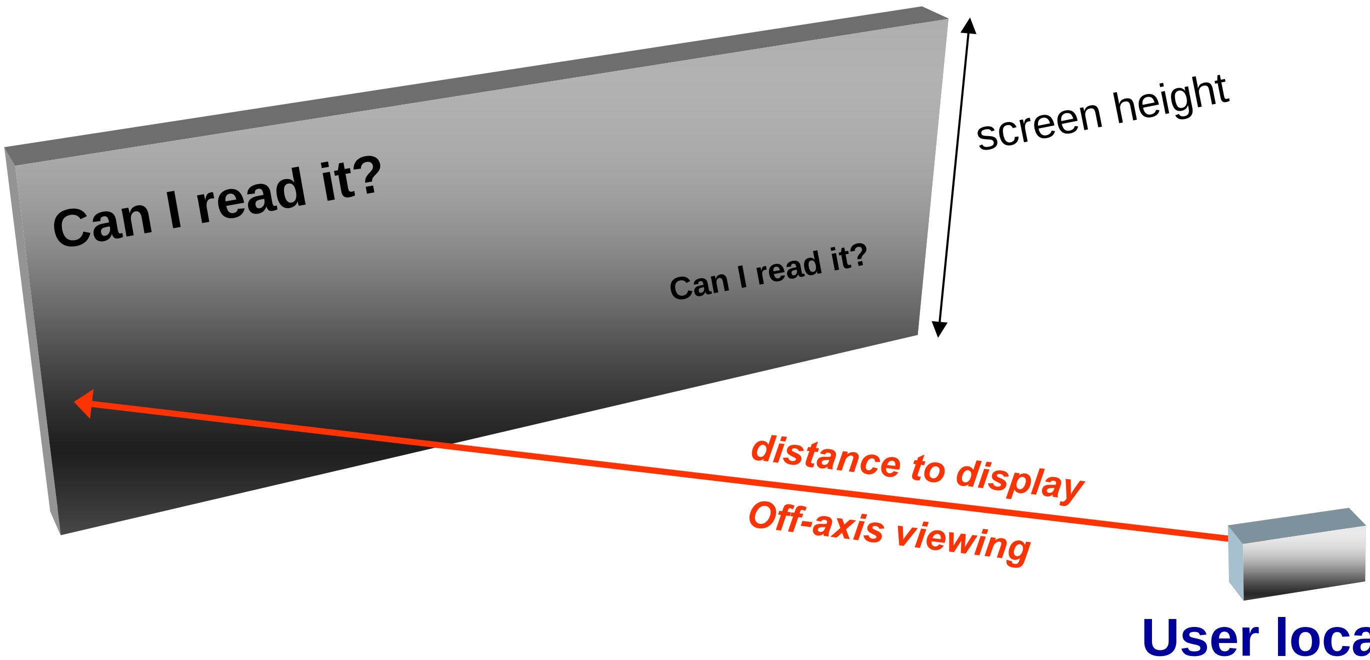
- Optimum – straight ahead
- Maximum – 60° left to right
- Optimum – 50° up or down



Source: Ebben (1998)

Text Size

- On-axis viewing
- Off-axis viewing



Contrast

Is the display bright enough?

- Contrast determines the range of discriminable gray shades
  - *Detail and continuous tone imagery*
- Larger viewing angles distort contrast on some displays
  - *+/- 30° horizontal, +/- 15° vertically*
- Contrast ratio is measured by the difference between full screen black and full screen white

Ambient Illumination

Non-task lighting

- Display interaction
  - *May reflect off display to viewer*
    - Can affect pupil aperture
  - *Can affect contrast by diluting full screen black*
  - *Can produce glare*
  - *Typical and hi-ambient lighting situations should be measured*

Readability

Can I see it? Can I read it?

- Location of the display
- Viewing angle and distance
  - *Head rotation*
  - *Eye rotation*
  - *Text size*
- Contrast
  - *Ambient illumination*
- Readability
- Color selection

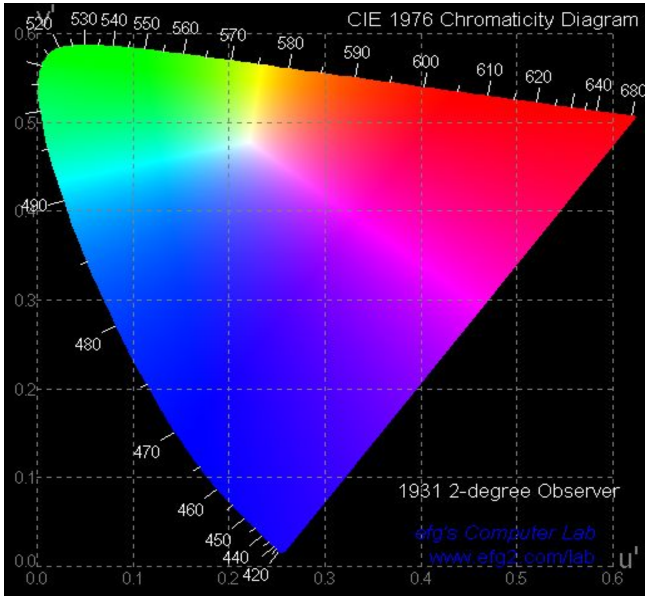
Readability

Can I see it? Can I read it?

- Location of the display
- Viewing angle and distance
  - *Head rotation*
  - *Eye rotation*
  - *Text size*
- Contrast
  - *Ambient illumination*
- Readability
- Color selection

Color Selection

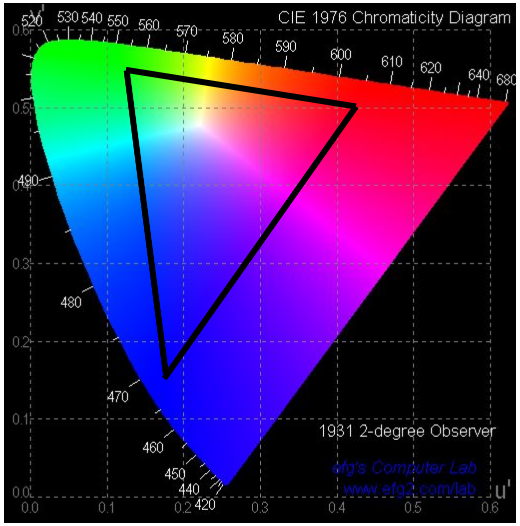
The range and combination of colors that can be seen by the ***human eye***



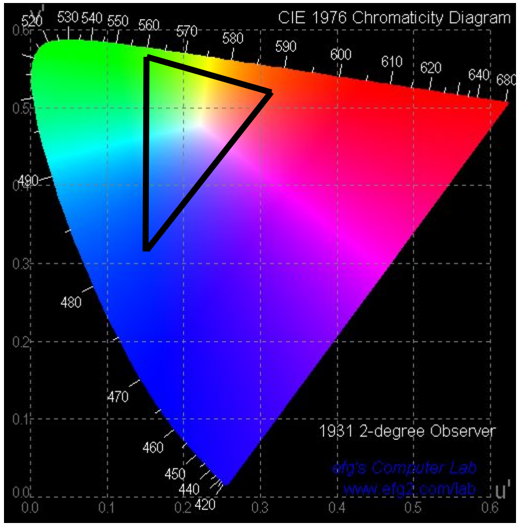
CIE Color Space

Color Selection

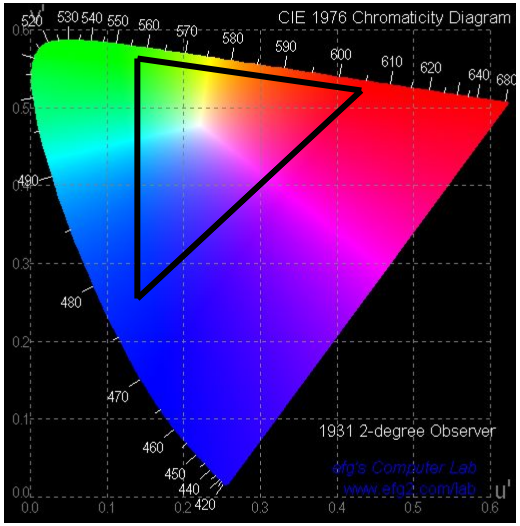
The range and combination of colors that can be produced by a ***display system***



LCD



Projection



Plasma

Recent Observations

Joint Expeditionary Force Exercise 2006

- Legibility problems
  - *Repeater displays; scaling problems*
- Color reproduction problems
  - *Red threat icons, brown map*

Workstation LCD

Shared projection display

Cognitive Issues

Can I use it?

- Defining group situation awareness
- Decision quality information

Computer information systems designed to facilitate **situation awareness** and **provide decision support**

Situation Awareness

Definition (Endsley, 1988)

- Perception of elements in a situation
- Understanding the elements
- Projecting future states

Situation Awareness

Global 2000 War Games

- Structured interviews with command elements
  - *All agreed – SA is a high priority**

C2 exercise

- Joint Force Air Component Commander's Headquarters (JFAC HQ)
  - *Large shared display v. small desktop*†
  - *Subjective ratings for mental workload and SA*
  - *No significant differences as a function of display size*

*Smallman, Oonk, & Moore (2000)

†Emery, Catchpole, Mackin, Dudfield, & Myers (2001)

Situation Awareness

Obstacles to achieving SA

- Defining group SA
- Relevant data
- Easy to understand

Path to facilitating SA

- Cognitive Task Analysis

Cognitive Task Analysis

Normative analytical tool

- Clarifying tasks and goals
  - *What tasks need to be performed?*
  - *What decisions needs to be made?*
  - *What information is needed to make those decisions?*
  - *Who will collaborate to complete task?*
- Observations are not enough
  - *Subject matter experts (SMEs)*
    - Interviews
- How shared display will support task performance

Information Sharing

Vital function of C2 environment

- Display communication/interaction*
  - *Pushing information*
  - *Pulling information*
- Multiple users
  - *Cognitive demands*
  - *Network overload*
  - *Recognizing simultaneous input*

*Mulgund, Travis, Standard, Means, & Burgman (2005)

Display Control

Less is more

- Individual or small team
- Possibly eliminate direct access

Guidelines for display control*

- Automation when possible to reduce error
- Someone to override automation
- Override should be identified
- Create and implement pre-sets

*Dugger & Barley (2000)

Recent Observations

Joint Expeditionary Force Exercise 2006

- **Cognitive issues**
  - *Display was under-utilized*
  - *Users felt information was useless to them*
  - *Some never even look at display (JEFX '04)**

*Darling & Means (2005)

Current AFRL/HE Research

Change awareness & detection

3D Display

Tailored COP (common operating picture)

Current Research

Change detection

- When did it change
  - *Alerts*
    - Location
    - Uni-sensory or multi-modal

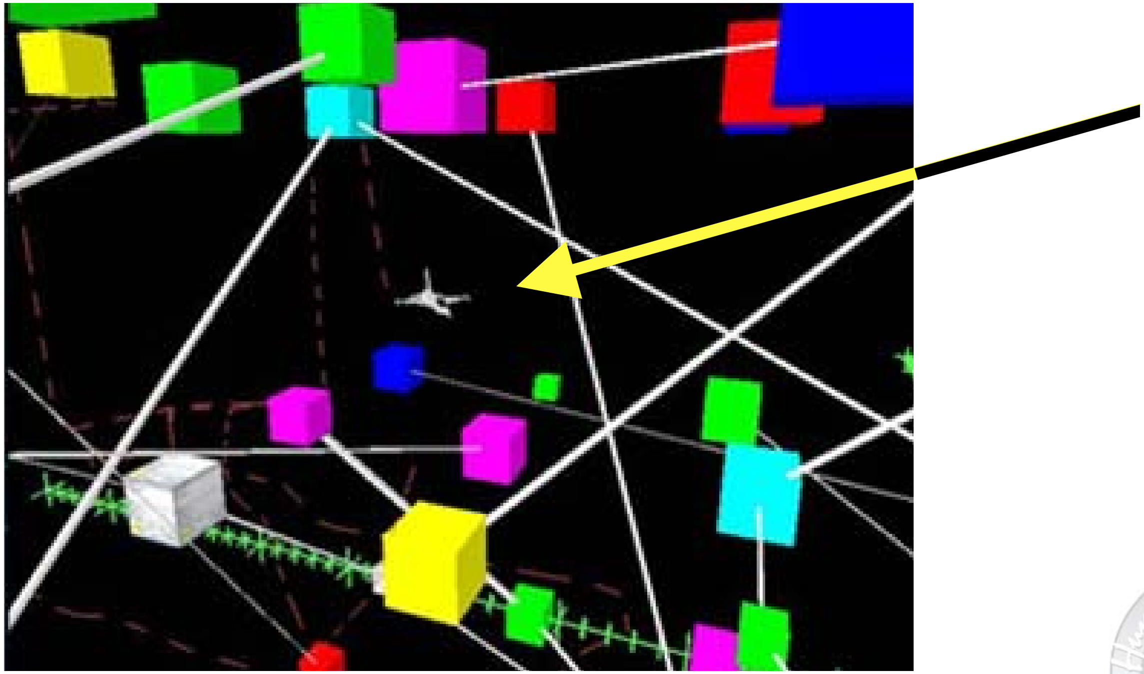
Change awareness

- What has changed
  - *Color, structure, new information, missing information*
  - *Time variable*

Current Research

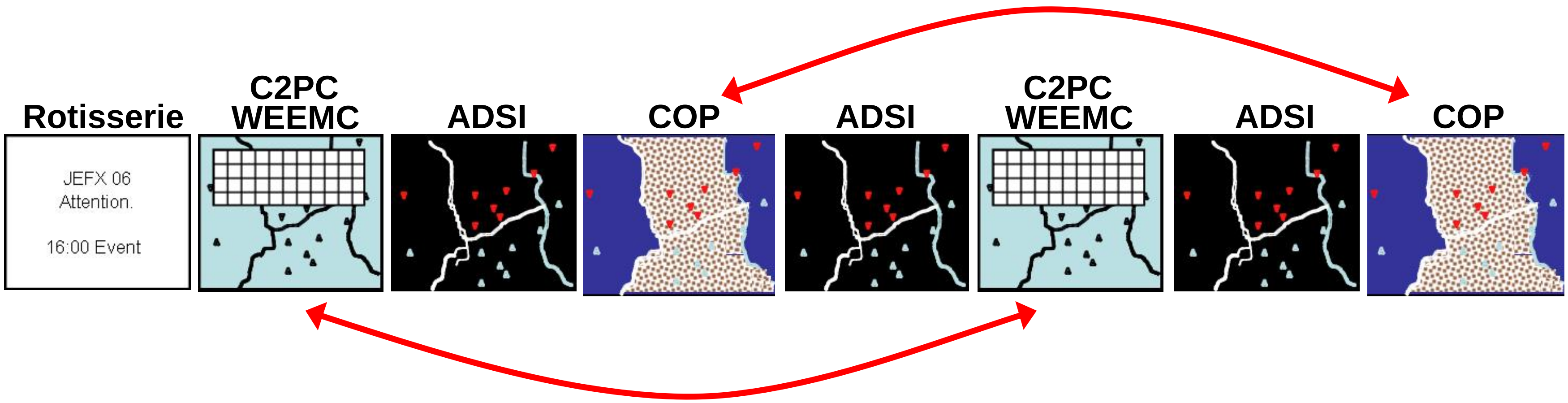
3D displays

- What tasks will benefit from 3D displays?
  - *2D*
  - *2.5D*
  - *3D*

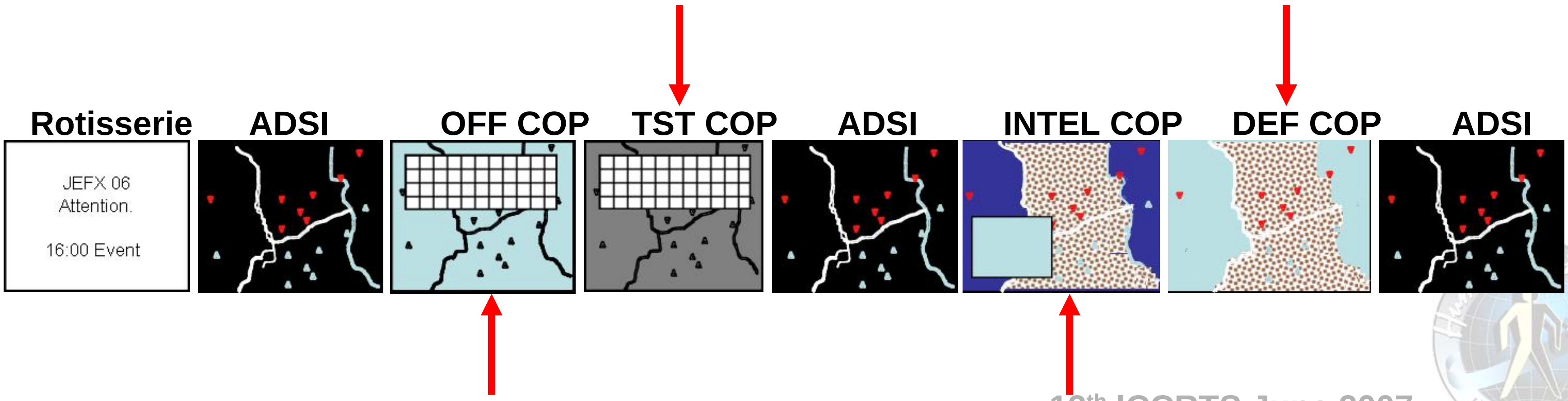


Tailored COP

JEFX '06 Combat Ops Data Wall



A Possible Solution



Summary

Perceptual issues

- The easier part

Cognitive issues

- The harder part
  - *Facilitating situation awareness*
  - *Providing decision quality information*
  - *Supporting decision making in a very complex environment*

Questions?